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CHAPTER 7

A SIMPLE NOMOGRAM FOR DETERMINATION OF ECHOCARDIOGRAPHIC LEFT VENTRICULAR GEOMETRY

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ABSTRACT

Background

Recent data have shown that left ventricular (LV) geometry provides additional information to the simple dichotomy of presence or absence of LVH, concerning the cardiovascular risk of hypertensive patients. A "new" class of concentric remodeling was created, discriminating a rather large group of hypertensive patients who do have increased risk despite no LV hypertrophy. As determination of LV geometry is not easy, our objective was to develop a nomogram enabling determination of LV geometry in a simple way.

Methods and results

The geometric classification is based on the combination of increased relative wall thickness and LV hypertrophy (LV mass index > 125 g/m^2), which are both calculated from wall thickness and end-diastolic diameter. In the nomogram the calculated cut-off lines for relative wall thickness and left ventricular hypertrophy are plotted, forming four quadrants which represent the geometric classes. Two nomograms are made: one based on Penn-convention measurement calculations and one based on American Society of Echocardiography-convention measurements.

Conclusion

Thus, this nomogram provides a simple way to determine LV geometry, and therewith a quick assessment of the additional cardiovascular risk of the hypertensive patient. This is especially important for those subjects with concentric remodeling, who would otherwise not have been identified as having increased risk for cardiovascular disease.

BACKGROUND

Investigation of left ventricular (LV) mass with echocardiography is one of the most widely used methods of determination of end-organ damage in hypertension. The occurrence of LV hypertrophy is associated with a clearly increased risk of cardiovascular disease.[1-4] While such a dichotomous classification is very useful in clinical practice, it does not accurately predict the cardiovascular risk for the individual subject, neither does it takes into account that increase of LV mass may follow different patterns. A novel classification was proposed by Koren, which not only takes into account the presence or absence of LV hypertrophy, but also of normal or increased relative wall thickness.[5] The 4 mutually exclusive classes thus created were shown to carry different cardiovascular risk, including the novel category of concentric remodeling: increased wall thickness without LV hypertrophy.[6] The problem is how to detect these categories easily in daily clinical practice. Another general problem in echocardiographic LV hypertrophy studies is the variety in indexation methods and measurement conventions as used in various studies. Also in both reports underlying the geometric classification different measurement conventions were used.[7] Our objective was to develop a simple nomogram for determination of LV geometry, based on mathematical calculation of the underlying formula, which should be useful in daily clinical practice to determine the LV geometric pattern and thereby enabling assessment of the attributable cardiovascular risk of the individual hypertensive patient. Two nomograms were developed, to be used with the Penn-convention measurements and with the American Society for Echocardiography-convention measurements.

METHODS AND FINDINGS

The geometric classification is based on the combination of presence of LV hypertrophy, and of increased relative wall thickness. Background to the development of this nomogram is that both LV hypertrophy and relative wall thickness are determined by the same echocardiographic measurements, being left ventricular wall thickness and end-diastolic dimension. In the nomogram lines are plotted representing the cutoff values for LV hypertrophy and relative wall thickness, based on values as derived from the original report of Koren [5]. The lines representing these cut-off values are determined using by the following formulas, given separately for the Penn-convention and American Society for Echocardiography-convention measurements.

LV mass index - Penn-convention

The formula for calculation of LV mass for Penn-convention measurements, with the correction of Devereux [7] is:

(1) $LV\ mass = 1.04\ [(IVS + PW + EDD)^3 - EDD^3] - 13.6;$

In which IVS = interventricular septal thickness, PW = posterior wall thickness, and EDD is end-diastolic diameter. This equation has too many variables to be solved analytically. As a first step, the average of the thicknesses of interventricular septum and posterior wall is used: the wall thickness. This can be done, as twice the wall thickness is by definition equal to the sum of the separate wall thicknesses of septum and posterior wall: $IVS + PW = 2 * WT$. We now can represent end-diastolic diameter by x and wall thickness by y, to solve this mathematical relation:

(2) $\text{LV mass} = 1.04\ [(2y + x)^3 - x^3] - 13.6$

This equation still can not be solved, but since cut-off values for LV hypertrophy are known, the left side of this equation can be calculated. The cut-off value for LV mass is defined as LV mass index = 125 g/m^2 according to Koren [5], indexed for body surface area (BSA): *LV mass index = LV mass /BSA*. (The formula for BSA is: $BSA = (height)^{0.725} * (weight)^{0.425} * 0.007184$

(weight: in kg; height: in cm) [8].) Implementing this in (2) gives:

(3) $LV\ mass\ index * BSA = 1.04((2y + x)^3 - x^3) - 13.6$

The final solution for solving this equation is entering of 4 predetermined values of body surface area: 1.6, 1.8, 2.0 and 2.2 m^2. Now, the formula can be solved mathematically step by step, for example for 2.0 m^2:

$125 * 2.0 = 1.04((2y + x)^3 - x^3) - 13.6;$ or

$(250 + 13.6)/1.04 = (2y + x)^3 - x^3;$ or

(4) $253.5 = 8y^3 + 12y^2x + 6yx^2$

This final equation has no analytical solution. However, by entering values for y, the corresponding values for x can be calculated by rewriting the formula to the general form of $ax^2 + bx + c = 0$:

(5) $(6y)x^2 + (12y^2)x + (8y^3 - 253.5) = 0$

which gives, by the general solution $x_{1,2} = (-b \pm \sqrt{}(b^2-4ac))/2a$:

$x_{1,2} = (-12y^2 \pm \sqrt{}(12y^2)^2 - 24y(8y^3 - 253.5))/12y$

Taking for instance y= 1 (cm):

$x_1 = (-12 - \sqrt{}6036)/12$ or $x_2 = (-12 + \sqrt{}6036)/12$; thus

$x_1 = -7.47$ or $x_2 = 5.47$

For the purpose of the nomogram, x_1 may be neglected because of its negative value; thus for wall thickness 1 cm and body surface area = 2.0 m^2, end-diastolic diameter is 5.47 cm. This calculation is repeated for all values for y between 0.6 and 1.6 cm of wall thickness (increment: 0.1 cm). The result is a number of values for wall thickness and end-diastolic dimensions through which an equation line can be drawn, representing LV mass index= 125 g/m^2 for body surface area = 2.0 m^2. This procedure is repeated for body surface area = 1.6 m^2, 1.8 m^2 and 2.2 m^2, from step (3) onwards.

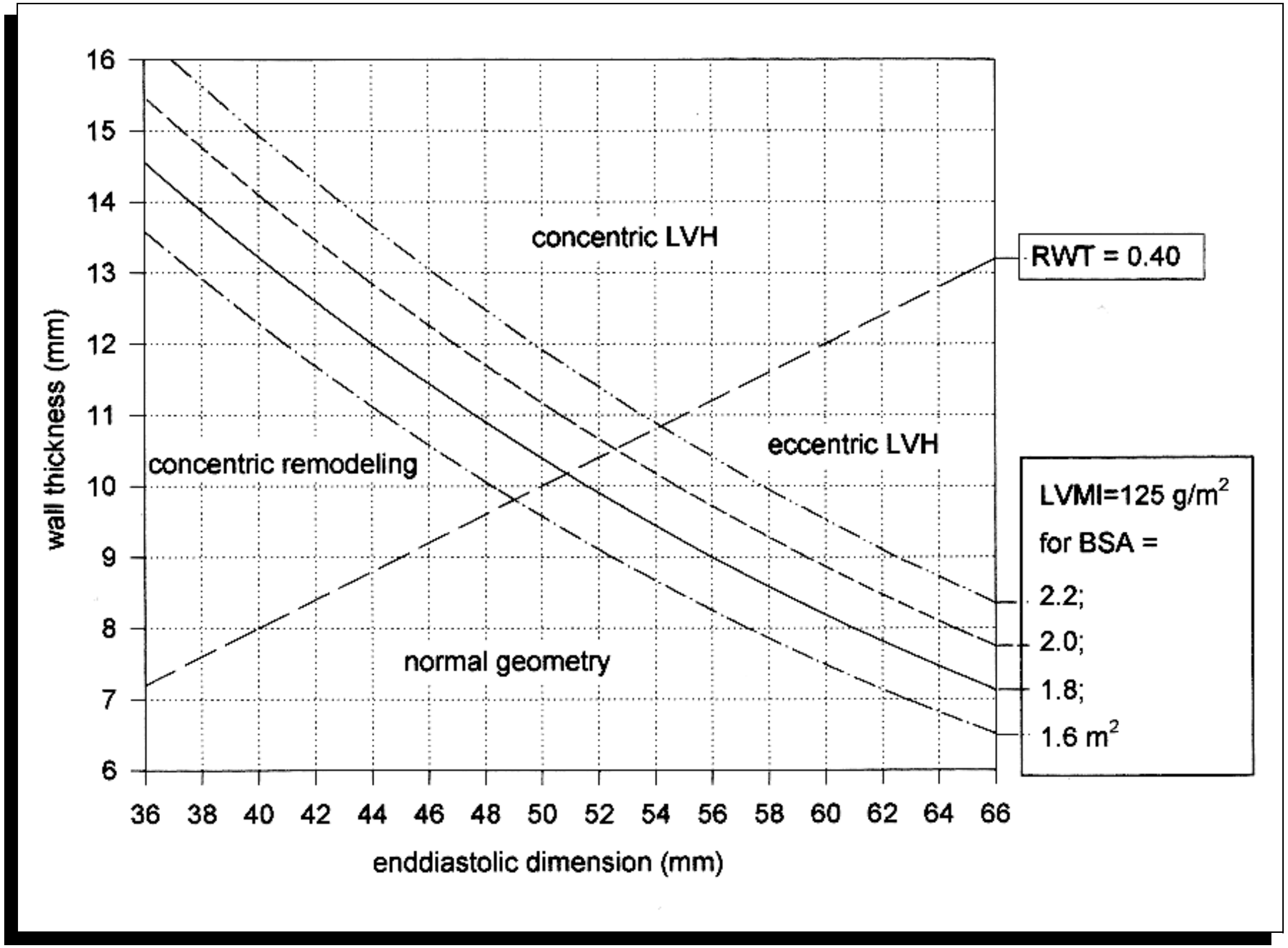

Figure 1.A: Nomogram for Penn-convention measurements

Cut-off lines for LVH (LVMI= 125 g/m^2) and RWT form four quadrants of LV geometry

Abbreviations: BSA= body surface area; LVH = left ventricular hypertrophy; LVMI = LV mass index

LV mass - ASE-convention measurements

The same mathematical procedure is repeated for the American Society for Echocardiography (ASE)-convention measurements. The formula for calculation of LVMI for the ASE-measurements according to Devereux [7] is:

$$LV\ mass = 0.80 * \{1.04[*(IVS + PW + EDD)^3 - EDD^3]) + 0.6$$

The same calculation steps are used as for the Penn-convention: replacement of EDD and WT with x and y:

(2) $$LV\ mass = 0.80 *(1.04*[(2y + x)^3 - x^3]) + 0.6$$

Followed by implementing LV mass = LVMI * BSA

(3) $$LV\ mass\ index * BSA = 0.80 *(1.04*[(2y + x)^3 - x^3]) + 0.6$$

Entering the cutoff value for LVMI (125 g/m^2) and BSA = 2.0 m^2 gives:

$$125 * 2.0 = 0.80 *(1.04*[(2y + x)^3 - x^3]) + 0.6\ ; \quad \text{or}$$

$$(250 - 0.6)/0.80 = 1.04*[(2y + x)^3 - x^3]; \quad \text{or}$$

(4) $$311.75/1.04 = 8y^3 + 12y^2x + 6yx^2,$$

which can be rewritten as

(5) $$(6y)x^2 + (12y^2)x + (8y^3 - 299.8) = 0$$

This formula can be used again to enter different values for y or wall thickness and calculating the corresponding values for x or end-diastolic dimensions, and this is repeated for the same body surface areas as done with the Penn-convention measurements (2.2, 2.0, 1.8 and 1.6 m^2).

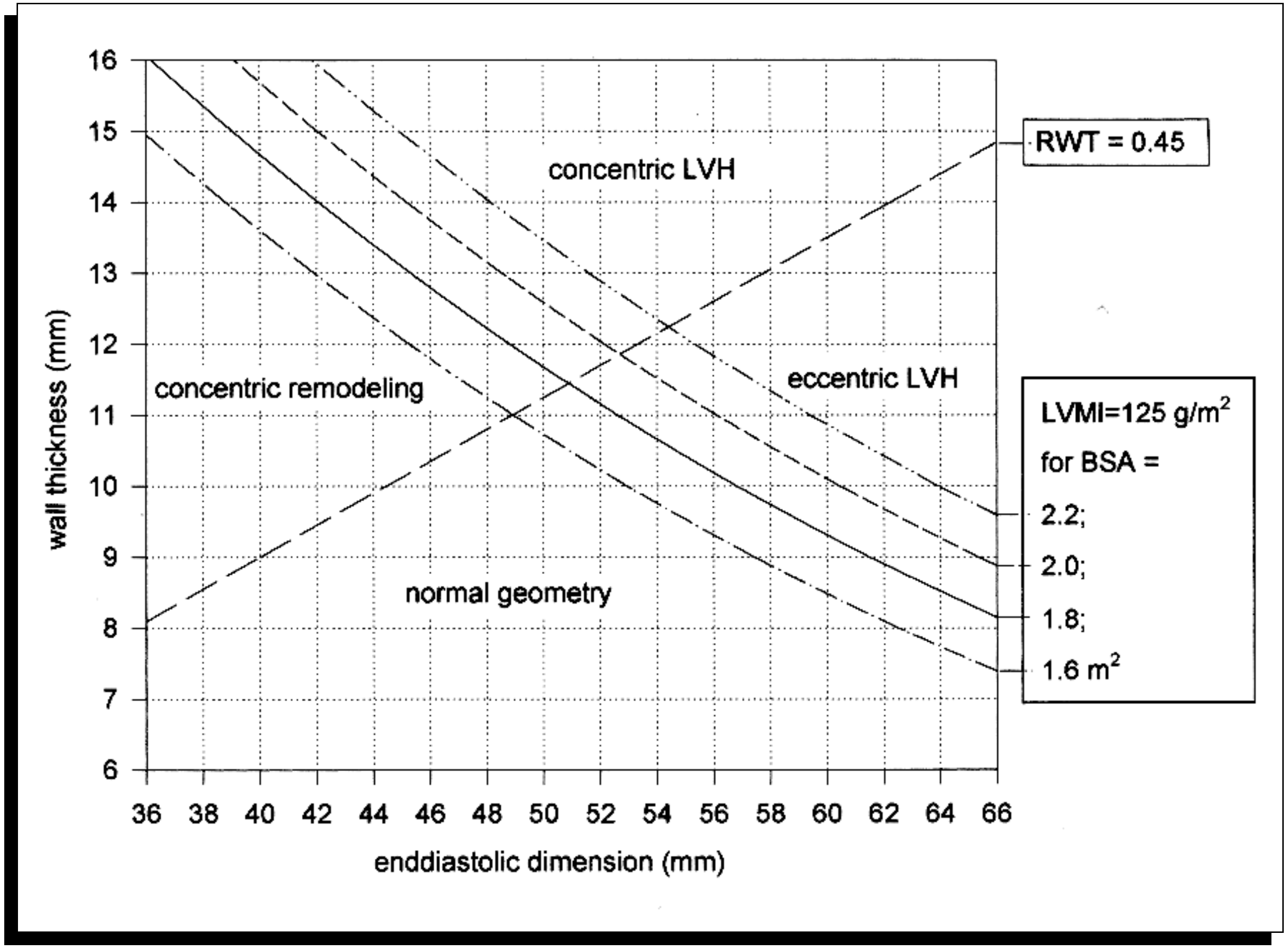

Figure 1.B: Nomogram for American Society of Echocardiography (ASE)-convention measurements.
Explanation and abbreviations: see figure 1.A.

Relative wall thickness

The relative wall thickness (RWT) is calculated by:

(6) $RWT = 2 * WT / EDD;$

where WT = wall thickness. The cut-off value for relative wall thickness, based on American Society for Echocardiography-measurements, is 0.45 [5,6]. Note that the variables are the same as those used for determining cut-off lines for LV hypertrophy; thus, this formula can also be rewritten as a mathematical equation using x and y, given RWT = 0.45:

$$0.45 = 2 * y / x \text{ ; or}$$

$$y = 0.225 * x$$

The resulting line representing this cut-off value of 0.45 can be plotted in the nomogram also. A problem is that for Penn-measurements no validated cut-off value for relative wall thickness is available. Recalling the difference between both measurement conventions as mentioned in the introduction, Penn-convention wall thickness measurements will be lower than ASE-measurements, and hence the cut-off value for relative wall thickness probably has to be lower. Based on our experience this difference is approximately 0.1 cm in wall thickness. With this, we can assess which relative wall thickness for Penn-measurements would correspond with RWT_{ASE} = 0.45. Two calculation examples: in case of American Society for Echocardiography-measurements of wall thickness (y) is 0.9 cm, the corresponding end-diastolic diameter (x) is 4.0 cm for RWT=0.45 . The same subject measured with Penn-convention would result in wall thickness 0.8 and end-diastolic diameter 4.2 cm, resulting in a RWT_{Penn} of 2*0.8/4.2= 0.38 . Another example: ASE: WT=1.6, and EDD = 71.1 for RWT_{ASE}=0.45 gives RWT_{Penn} = 0.41. Thus, in absence of validated cut-off values for Penn-convention measurements, the approximate value for RWT would be around 0.40. The resulting line:

$$y = 0.2 * x$$

is plotted in the nomogram (figure 1.B).

Plotting of nomogram, and patient example

Both obtained cut-off lines for RWT and for LVH can be plotted in the same nomogram, since the underlying x or EDD and y or WT are identical. In the final nomogram, these two lines form four "quadrants" of geometry. With this, the geometric classification of a hypertensive subject can be derived by plotting the individual values for wall thickness and for end-diastolic dimensions in the nomogram. Figure 1.A presents the nomogram for measurements according to the Penn-convention, and 1.B for ASE-convention measurements. In both nomograms three different lines are given for LVH, representing three body surface areas. The cut-off line for RWT in the Penn-convention nomogram is based only on the assumptions as made above. A range of wall thickness from 6 to 16 millimetres was selected based on clinical judgement of observed "normal" values in hypertensive patients; similarly, the range of end-diastolic values was chosen from 36 to 66 millimetres. In the lay-out, we chose millimetres instead of centimetres, as standardly provided by most echocardiographic equipments.

From the nomogram, the LV geometric classification can now be determined easily. This can be illustrated with two examples measured according to the Penn-convention: For instance, one subject has an average wall thickness of 10 mm, with end-diastolic diameter of 56 mm, and the body surface area is about 1.6 m^2. Plotting of these values shows that the LV geometric pattern is eccentric hypertrophy. Note that with the same values, a subject with a body surface area of 2.2 m^2 would have a normal geometry. Another example: average wall thickness 11 mm and end-diastolic diameter 50 mm, with body surface area about 1.8 m^2: LV geometric pattern is concentric hypertrophy. Again, for the same measurements but for body surface area 2.2 m^2, the pattern would be concentric remodeling.

DISCUSSION

This nomogram provides a simple way to determine LV geometry, allowing quick assessment of the additional cardiovascular risk of hypertensive patients in daily clinical practice. Often, only the separate echocardiographic values of LV measurements are known. This does not enable determination of the presence of abnormal geometric patterns, except for obvious cases of LV hypertrophy. Perhaps even more important is the detection of the "new" category of concentric remodeling (increased relative wall thickness without LV hypertrophy), which is also not easy to recognize without complex calculations for each individual patient. This recognition is important, because the prevalence of this risk-bearing pattern is rather high, from about 13% to up to 40% in hypertensive populations. [9-12] Using the nomogram, the presence of concentric remodeling can be determined easily, thereby discriminating a group of patients who would not have been considered at increased cardiovascular risk due to the absence of LV hypertrophy. The nomogram can also facilitate detection of LV hypertrophy, and furthermore, different patterns of hypertrophy: concentric versus eccentric, although it is not clear yet whether a difference does exist between these two patterns in attributable cardiovascular risk.[13] It should be noted that the nomogram can only be used in hypertensive populations, as no information on cardiovascular risk and LV geometry is available for patients with other underlying heart diseases such as aortic stenosis, ischemic heart disease or cardiomyopathies.

The validity of the present nomogram with its associated criteria is based on two independent studies, showing positive relations while using the same cut-off values and indexation methods (LV hypertrophy > 125 g/m^2 for males and females) [5,6]. However, even these two studies do have some differences in methodology. In the original study of Koren the Penn-convention was used for calculation of LV mass index while the American Society of Echocardiography-convention was used for calculation of relative wall thickness[5] , while in contrast Verdecchia used the American Society for Echocardiography-convention for both measurements.[6] The major problem is not LV mass index, since different and validated correction formulas are available.[7] However, no such correction is known for relative wall thickness: in fact as both Koren and Verdecchia used the American Society for Echocardiography-convention, no validated cutoff values for relative wall thickness for the Penn-convention measurements are available. As shown, an approximate corresponding value can be calculated, but this cutoff value needs to be confirmed. A second difference between both studies is which wall thickness of the left ventricle should be chosen for calculation of LV geometry. While in the original study of Koren thickness of the posterior wall was used, Verdecchia et al. could establish a significant difference in cardiovascular risk only when analyzing the average of posterior wall and interventricular septal, not by posterior wall thickness alone.[6] Considering these results, we propose to use the average of both, which appear to give more reliable data also than with use of one single wall thickness.[14]

One drawback of the nomogram is one that arises in LV hypertrophy studies in general: that of the variety in cut-off values and indexation methods. Cut-off values for LVH may or may not be gender-specific, in some studies LV mass is indexed for BSA whereas in other this is done for height. [1-7, 15,16] In a report from the Framingham study,[15] different LVH values (gender-specific) and indexation methods (by height) were used when compared with Koren and Verdecchia.[5,6] In this study a different risk was observed also for the different geometric classes, although it was discussed whether this may be due to differences in LVMI among the classes.[17] With regard to RWT, different cut-off values dependent upon age have been proposed.[18] All these differences in indexation, cut-off values and adaptations are important and form a general problem in echocardiographic studies in hypertension. However, they do not necessarily affect the usefulness of this nomogram, as it can be easily adapted to any desired method of indexation or LVH values if desired so - only the cut-off lines in the nomogram need to be changed. Furthermore, a recent report comparing different criteria for LVH did not show large differences among seven different LVMI cutoff values, with the gender-independent value of 125 g/m^2, as used in this geometric classification, being among the better predictors of cardiovascular risk.[19]

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